BELLCOMM, INC.
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B71 02040

SUBJECT: Propulsion/Power Mid-Term Reviews, NAR Phase B Space Shuttle, January 13 and 14, 1971 - Case 237

DATE: February 23, 1971

FROM: C. Bendersky

ABSTRACT

The North American Space Division (NAR) Phase B Space Shuttle Propulsion and Power mid-term review is described and discussed herein. The review presented the results of trade studies and recommended baseline configurations for the following subsystems: main rocket propulsion, attitude control and orbit maneuvering propulsion, auxiliary power, electrical, and hydraulic. The new baseline will be used in the configuration preliminary designs which are to be performed in the final portion of the Phase B study.

Many of the trade study results were based on configurations which were presented at the time of the quarterly review. Since that time the vehicle gross lift-off weight has increased significantly. The present baseline recommendations are primarily based on extrapolations of the earlier configuration trade study results. Several recommendations particularly in the on-orbit propulsion area, although probably valid, do not appear to be based on clear cut superiority. Nevertheless, the recommended systems for preliminary design should be satisfactory to obtain the overall aims of the Space Shuttle Phase B activity.

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MEMORANDUM FOR FILE

1.0 INTRODUCTION

The North American Rockwell Space Division (NAR) presented their Phase B Space Shuttle Propulsion and Power 180-day mid-term reviews at MSC on January 13 and 14, 1971. The propulsion and power reviews were two of many "splinter group" meetings each of which were concerned with major technical discipline areas.[1] The main purposes of the mid-term review were to present the results of the systems trades, recommend revision to the study baseline and select the configurations and subsystems to be carried into the preliminary design phase which is the major effort of the second half of the Space Shuttle Phase B studies.

The subsystems areas and trade topics covered in the propulsion and power splinter group meetings[2] were as follows:

1. Main rocket propulsion system (MRP)

2. Attitude control propulsion systems (ACPS) trade study results

3. Separate on-orbit maneuvering systems (OMS) trade study results

4. Auxiliary power unit (APU), electrical and hydraulic system baseline descriptions.

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[1]A summary review of the entire Phase B mid-term study status was presented the afternoon of January 13, 1971. Those highlights are recorded in "Space Division North American Rockwell, Phase B Space Shuttle, Mid-Term Review, MSC, January 13, 1971," by C. Bendersky, dated January 19, 1971.

[2]The airbreathing engine system trade study results are presented in a separate splinter meeting held the previous week. The results are described in "Shuttle Airbreathing/Propulsion Briefing by North American/Convair and Shuttle Airbreathing Propulsion Subpanel Meeting at MSC on January 6, 1971," by J. J. Schoch, dated January 20, 1971.

The General Dynamics Astronautics Company (GDC) under subcontract to NAR is responsible for the booster vehicle studies. As such GDC personnel reported the study results on the above topics for the booster configuration.

This memo describes the present propulsion and power baseline recommended for inclusion into the preliminary design phase and describes some of the background leading to the present baseline selections.

2.0 PROPULSION AND POWER BASELINE RECOMMENDED FOR PRELIMINARY DESIGN

The NAR Space Shuttle Phase B studies are presently scheduled to provide preliminary designs of two, 2-stage fully recoverable configurations having essentially the same booster design matched to either a low cross range (LCR) orbiter or a high cross range (HCR) orbiter. The booster configuration is a single body canard delta wing configuration. The HCR orbiter has a delta wing and the LCR orbiter a straight wing. Table 1 lists the gross lift-off-weight (GLOW) of both present HCR and LCR configurations and for reference lists the total GLOW of the HCR and LCR configurations at the time of the quarterly review. Since that time, due to changes in study baselines, the HCR GLOW has increased from 3.8 M lb to 4.8 M lb and the LCR GLOW has increased from 3.5 M lb to 4.4 M lb. The major cause of the weight increase was the substitution of JP-4 fueled airbreathing engines for the previously ground-ruled hydrogen fueled systems. These large increases of GLOW's require a concomitant increase of total gross lift-off thrust. NAR proposed to obtain this increase by uprating (resizing) the thrust of the individual MRP engines while maintaining the same total number (12) chosen for the LCR booster design as presented during the 90-day quarterly review. At that quarterly review the engine sea level thrust was baselined at 415 K lb thrust. To maintain proper levels of take-off thrust-to-weight, a sea level engine thrust level of 540 K lb for the HCR booster or 500 K lb for the LCR booster is now recommended.[3] Two-engine installations for both the HCR and LCR orbiters are proposed. For orbiter use nozzle extensions would be added to the sea level engines consistent with base dimension limitations. The HCR orbit propulsion would then provide 620 K lb vacuum thrust and the LCR orbiter, 574 K lb vacuum thrust. Acceptance of the NAR MRP uprating recommendations would have a major impact on the on-going MRP Phase B studies and the planning for the FY'72 MRP Phase C/D procurement.

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[3] It was inferred that NAR would request that the LCR configuration be dropped from the Phase B study.

The baseline reference mission used in the trade studies of both LCR and HCR configurations is presented in Figure 1. The orbiter trade studies were used to size the ACPS thrusters. The booster ACPS was then designed to use the same thruster hardware. The orbiter configurations had a partially integrated ACPS and OMS. That is, although the ACPS and OMS thrusters were different, many of the propellant supply and fuel systems elements were common and functioned in both ACPS and OMS operating modes. Figure 2 presents the ACPS/OMS characteristics and Figure 3 displays the thruster locations for both the straight wing LCR and delta wing HCR orbiters. Figure 4 displays the common tankage propellant requirements for the HCR orbiter and shows the usage breakdowns for ACPS and OMS. The tankage system is also typical for the LCR orbiter. The orbiter ACPS have twenty-nine 2100 lb thrust thrusters operating at 300 psia chamber pressure using liquid propellants supplied from gas generator driven turbopumps. The H_2 and O_2 propellants are stored as subcritical liquids. The OMS turbopumps are used to provide high pressure liquids directly to the OMS thrusters and to gas generator and heat exchanger components in which LH_2 or LO_2 are gasified and stored in accumulators at 1000 psia. During OMS operation, gases from the accumulators are supplied to the tankage to pressurize the propellants. The accumulators are discharged to 500 psia before it is necessary to refill them.

The thruster locations and line schematic of the booster ACPS are shown in Figure 5. The booster ACPS has 22 of the same thrusters (2100 lb vacuum thrust) chosen for the orbiters. The system is sized to provide 10^6 lb-sec of impulse for attitude control with a 150 lb-sec minimum impulse bit. The ACPS propellants are stored as subcritical liquids. Sufficient capacity is provided to supply the booster auxiliary power systems. The booster ACPS and APU systems are integrated and use the same gas generators, turbopump and accumulators as is shown in Figure 6. The turbopumps are required to have 10:1 throttling to satisfy both ACPS and APU duty cycles. The booster APU will be further described in a succeeding paragraph.

The orbiter power generation system baseline is described in Figures 7 and 8. The electrical power system is designed to a fail operational/fail operational/fail safe (FO/FO/FS) criteria, and the APU system, to a FO/FS criteria. The orbiter APU system is completely independent of the ACPS and has 4 units driven by gaseous O_2 and H_2 gas generators which are sized to provide 139 HP for the LCR orbiter or 173 HP for the LCR orbiter. Both propellants are stored as supercritical fluids. Electrical heaters located inside the propellant tanks provide the energy to maintain the storage pressures. The HCR orbiter and the LCR orbiter hydraulic system configuration is shown in Figure 9 and Figure 10, respectively. Four independent 4000 psia systems were selected. A general description of the systems is presented in Figure 11.

The booster APU requirements are displayed in Figure 12. As mentioned previously the booster ACPS and APU are integrated. Figure 13 displays the ACPS and APU equipment location. (As shown in Figure 13, the booster environmental control system (ECS) is also partially integrated with the ACPS and APU.) Figure 14 is a schematic of the APU and includes a weight estimate of the system. Each APU is rated at 487 HP. Figure 15 presents a load profile.

3.0 COMMENTARY

The NAR and GDC presentations were comprehensive and detailed. However, most of the detailed trade studies were based on the configurations presented at the 90-day quarterly review. Apparently these results were then extrapolated to the present heavier configurations. However, I cannot quarrel with the NAR/GDC selection of baseline concepts or subsystems. Although NAR and GDC did select common ACPS thrusters and probably will choose a common APU, the booster and orbiter studies were carried out independently and the results not fully coordinated. I believe that closer coordination between both companies may provide a fruitful improvement in the actual system design which is to be the major remaining effort of the Phase B study.

3.1 ACPS

NAR provided sufficient engineering data to show the superiority of the high pressure ACPS concepts over the low pressure concepts which use passive heat exchangers. The conclusions were based on the 90-day quarterly configuration. Thermodynamic study results showed that the low pressure booster tank mounted heat exchangers could not function satisfactorily for short ascent modes, e.g., 100 nm due East, or in a once-around abort mode. These results combined with the admitted heavier weight of the low Pc system was sufficient to justify selection of the high pressure pump-fed ACPS.

3.2 Separate OMS

Separate OMS engines were clearly shown to be weight and cost superior to using the same ACPS thrusters for OMS operation. Again these trade studies were based on the quarterly configurations, but have enough margin to be conclusive. The selection of the type of OMS engine and the value of OMS component integration with the ACPS is not as clear cut. For example, the OMS trade studies compared new engines with RL-10 engines or its derivatives. The real criterion which favored the new engine selection over RL-10's was based on a specification of 20,000 lb minimum OMS thrust to assist orbiter abort in an orbiter one MRP engine-out failure mode. This criterion established the desire for three 10,000 lb thrust engines (one OMS engine-out F/O criterion) and required three RL-10's (or 2 new uprated 20,000 lb thrust RL-10 derivatives). On this basis the new 10,000 lb engine was lighter and more cost effective than the RL-10. With a new MRP thrust engine under consideration, a revision of the presently specified MRP maximum emergency power level (EPL) may now be considered. An upward revision of only 1 percent EPL would reduce the minimum one engine-out OMS thrust to 14,000 lb and would allow the use of the present 15,000 lb thrust RL-10. Thus a 2 RL-10 OMS would satisfy the present one MRP engine-out abort criterion at a significant weight and cost savings. This option should be considered prior to final OMS selection.

The value of OMS/ACPS subsystem integration was not convincingly proven. The option of completely separate systems again should be kept open particularly after the booster and orbiter ACPS/APU studies are reviewed for commonality impact.

C. Bendersky

1013-CB-klm C. Bendersky

TABLE 1

MID-TERM VEHICLE WEIGHT ESTIMATES

	HIGH CROSS RANGE	LOW CROSS RANGE
BOOSTER		
TYPE	DELTA WING CANARD	DELTA WING CANARD
GLOW (LB)	3.889×10^6	3.590×10^6
MRP, NO	12	12
MRP SEA LEVEL THRUST (LB)	540 K	500 K
ORBITER		
TYPE	DELTA	STRAIGHT WING
GLOW (LB)	935.4×10^6	852.5×10^6
MRP, NO	2	2
MRP VAC THRUST (LB)	620×10^3	574×10^3
TOTAL GLOW (LB)	4.824×10^6	4.443×10^6
QUARTERLY REVIEW CONFIGURATION GLOW (REFERENCE) (LB)	3.789×10^6	3.531×10^6

5

BASELINE REFERENCE MISSION

(1) STRAIGHT WING ORBITER
(2) DELTA WING ORBITER

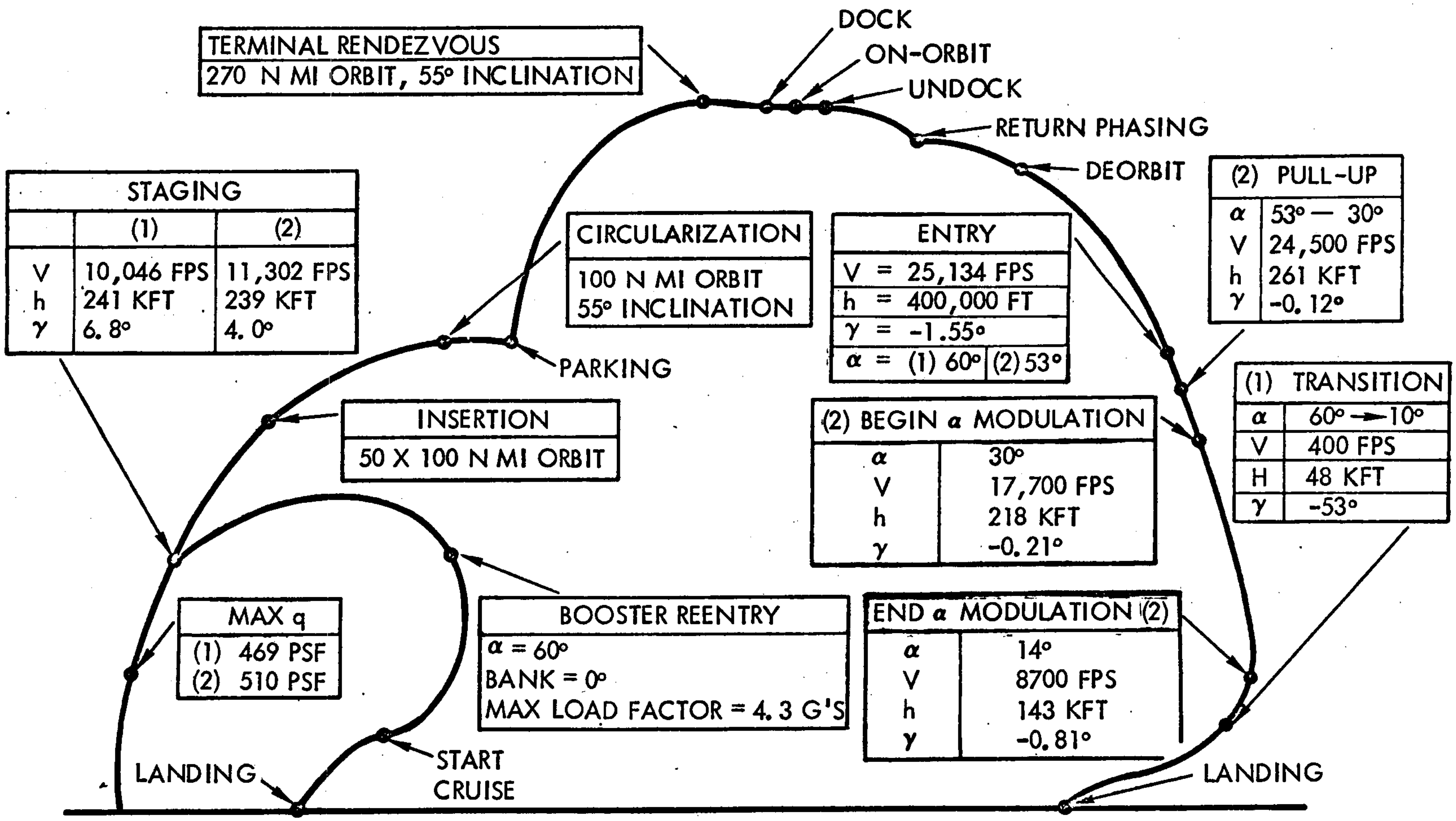


FIGURE 1

BASELINE ON-ORBIT PROPULSION SYSTEM CHARACTERISTICS

- CONCEPT - INTEGRATED OMS / ACPS
- ENGINES / THRUSTERS

OMS:	3 - 10,000 lb Thrust
	800 PSIA Pc
	255:1 Area Ratio
	5.0:1 Mixture Ratio (System)
ACPS:	29 - 2100 lb Thrust
	300 PSIA Pc
	20:1 Area Ratio
	3:1 Mixture Ratio (System)

- PROPELLANT

HIGH CROSSRANGE		LOW CROSSRANGE	
LH_2	LO_2	LH_2	LO_2
2109 FT^3	592 FT^3	1878 FT^3	529 FT^3
7038 LB	31127 LB	6241 LB	27699 LB

- SYSTEM WEIGHT

- DRY	14021 LB	11998 LB
- LOADED	52186 LB	45938 LB

FIGURE 2

ACPS CONFIGURATION

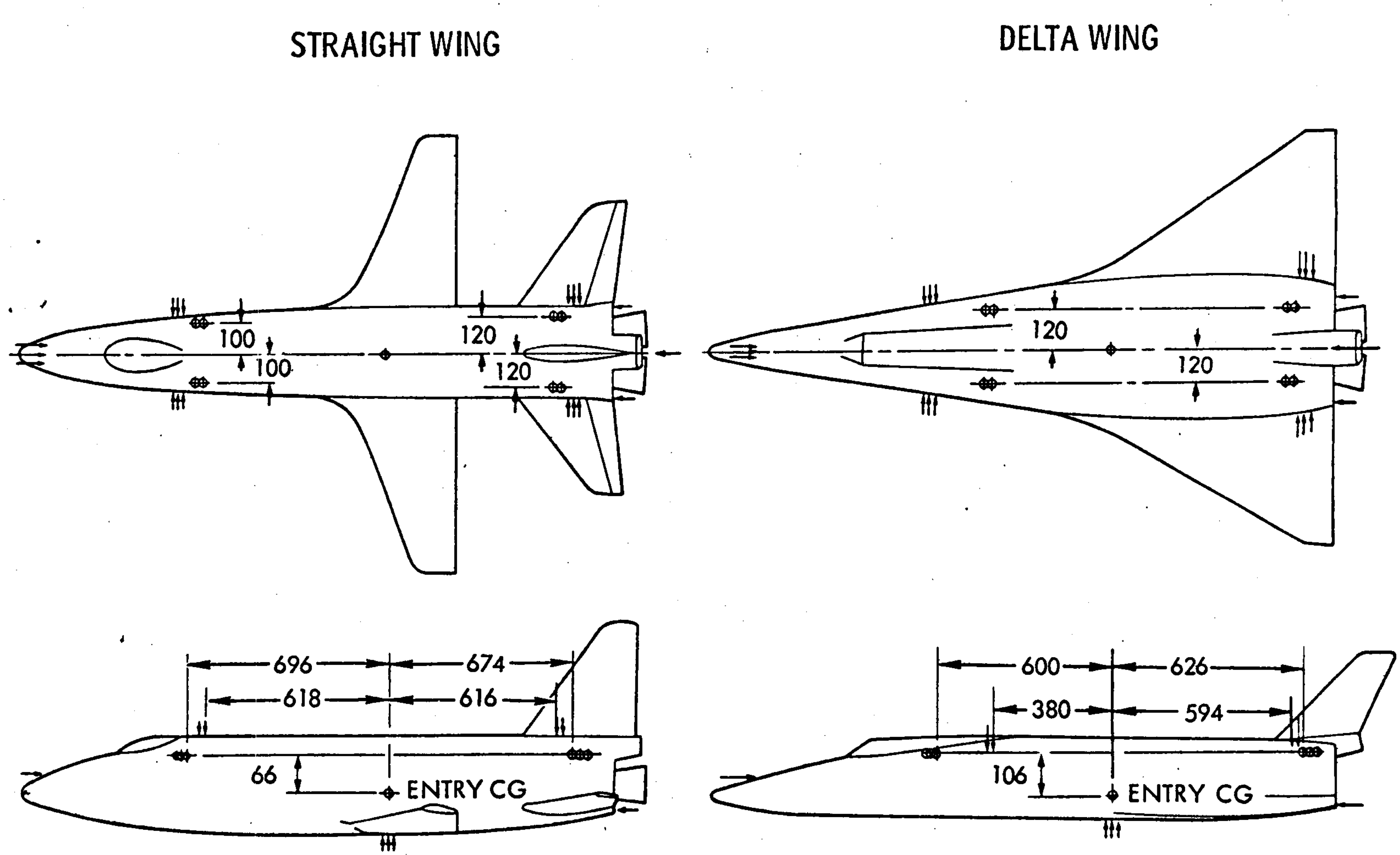
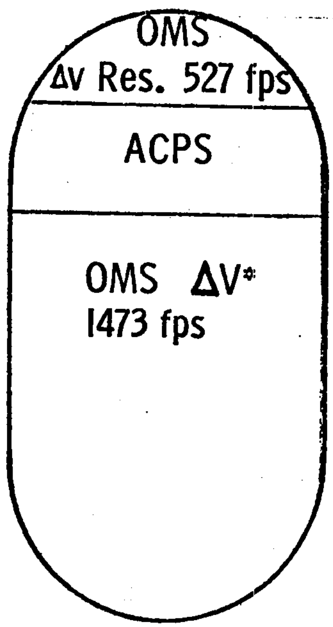


FIGURE 3

ORBIT PROPULSION TANKAGE

High Cross Range Orbiter

LH_2 TANK



0 lb
397 ft^3
1,360 lb
309 ft^3
5,680 lb
1,403 ft^3

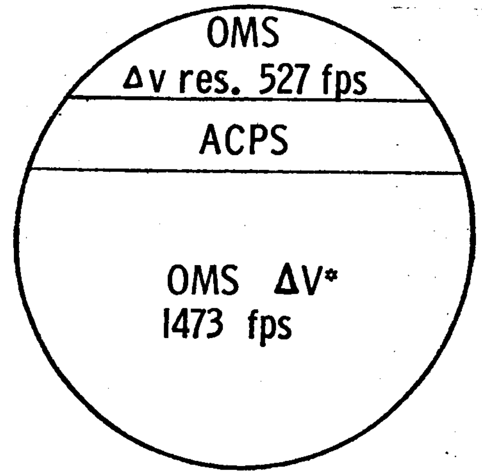
TOTALS

7,040 lb
2,109 ft^3

TANK WEIGHT (2)

OMS	3888 lb
ACPS Delta	434 lb
Total	4322 lb

LO_2 TANK



0 lb
123 ft^3
4,084 lb
57.4 ft^3
27,046 lb
412 ft^3

TOTALS

31,130 lb
592 ft^3

TANK WEIGHT (1)

OMS	1166 lb
ACPS Delta	100 lb
Total	1266 lb

*INCLUDES ULLAGE, RESIDUALS, PRESSURANT, BOILOFF AND MR ALLOWANCE

FIGURE 4

ACPS & ENVIRONMENTAL CONTROL SYSTEM LINES

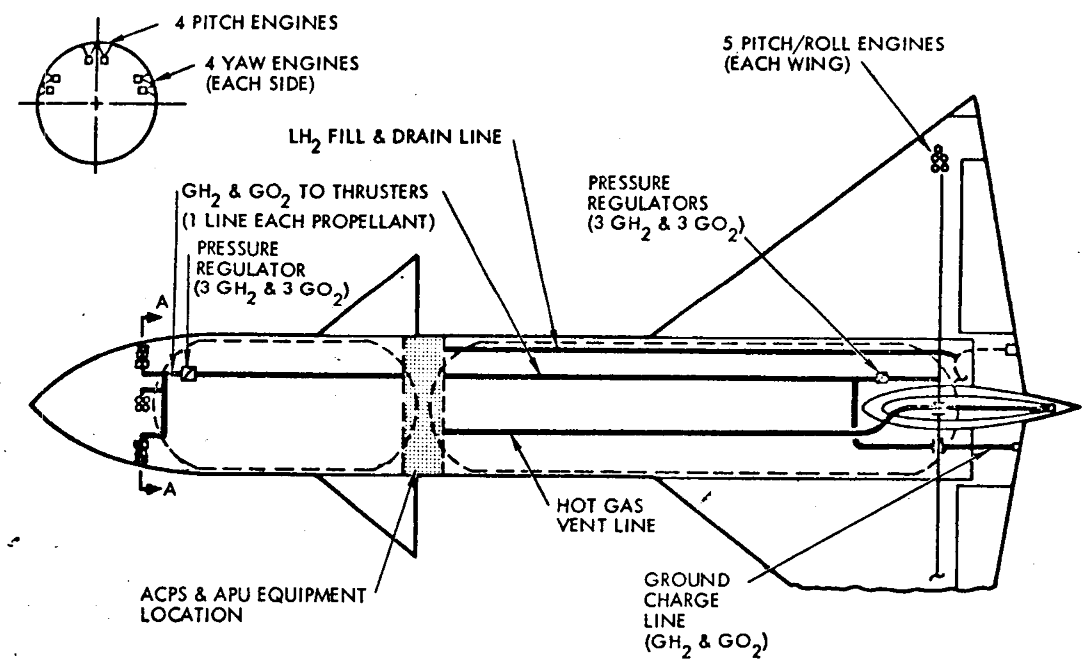


FIGURE 5

TURBOPUMP FED ACPS & APU

DETAILED SCHEMATIC

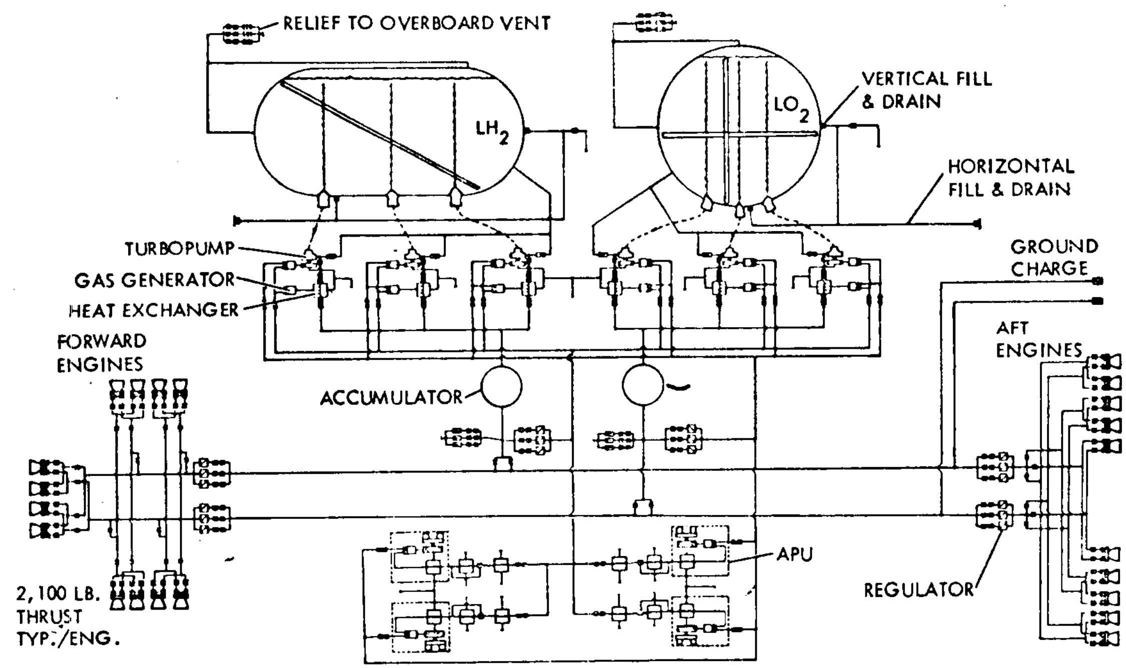


FIGURE 6

ORBITER POWER GENERATION SYSTEM BASELINE

ELECTRICAL POWER (FO/FO/FS)	
• VOLTAGE	29V DC ± 5%
• FUEL CELLS	4 X 7 KW CONT/10 KW PK
• BATTERY - EMERGENCY	2 X 10AH (NI-CD)
• AC GENERATORS	DRIVEN BY APU'S
• HEAT REJECTION	INTEGRATED WITH ECLSS
APU SYSTEM (FO/FS)	
• RATINGS - STRAIGHT WING	4 X 139 HP
- DELTA WING	4 X 173 HP
• TYPE	H_2/O_2, 250 PSIA
• AC GENERATOR RATING	4 X 20/30K VA, 120/208V AC, 400 Hz

FIGURE 7

ORBITER POWER GENERATION SYSTEM BASELINE (CONT)

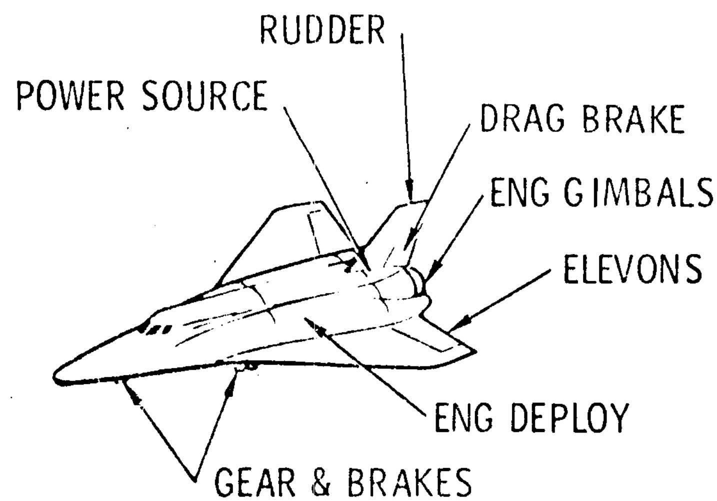
POWER GENERATION CRYO TANKS (FS)

• SUPERCRITICAL STORAGE		H_2: 300 - 350 PSIA
		O_2: 800 - 900 PSIA
• EXPULSION - FUEL CELLS & ECLSS		ELECT HEATERS
- APU'S		HEATED GAS
• STRAIGHT WING -	H_2 TANKS (2 EA)	67 IN. OD, 276 LB FLUID EA
-	O_2 TANKS (2 EA)	37 IN. OD, 730 LB FLUID EA
• DELTA WING -	H_2 TANKS (2 EA)	74 IN. OD, 372 LB FLUID EA
-	O_2 TANKS (2 EA)	39 IN. OD, 813 LB FLUID EA

FIGURE 8

HYDRAULIC SYSTEM
DELTA-WING ORBITER CONFIGURATION

- -161B CONFIG
- FOUR INDEPENDENT SYSTEMS
- 4000 PSI SYSTEM
- 173 HP APU



*AUX MTR PUMP OPN FOR ZERO-G

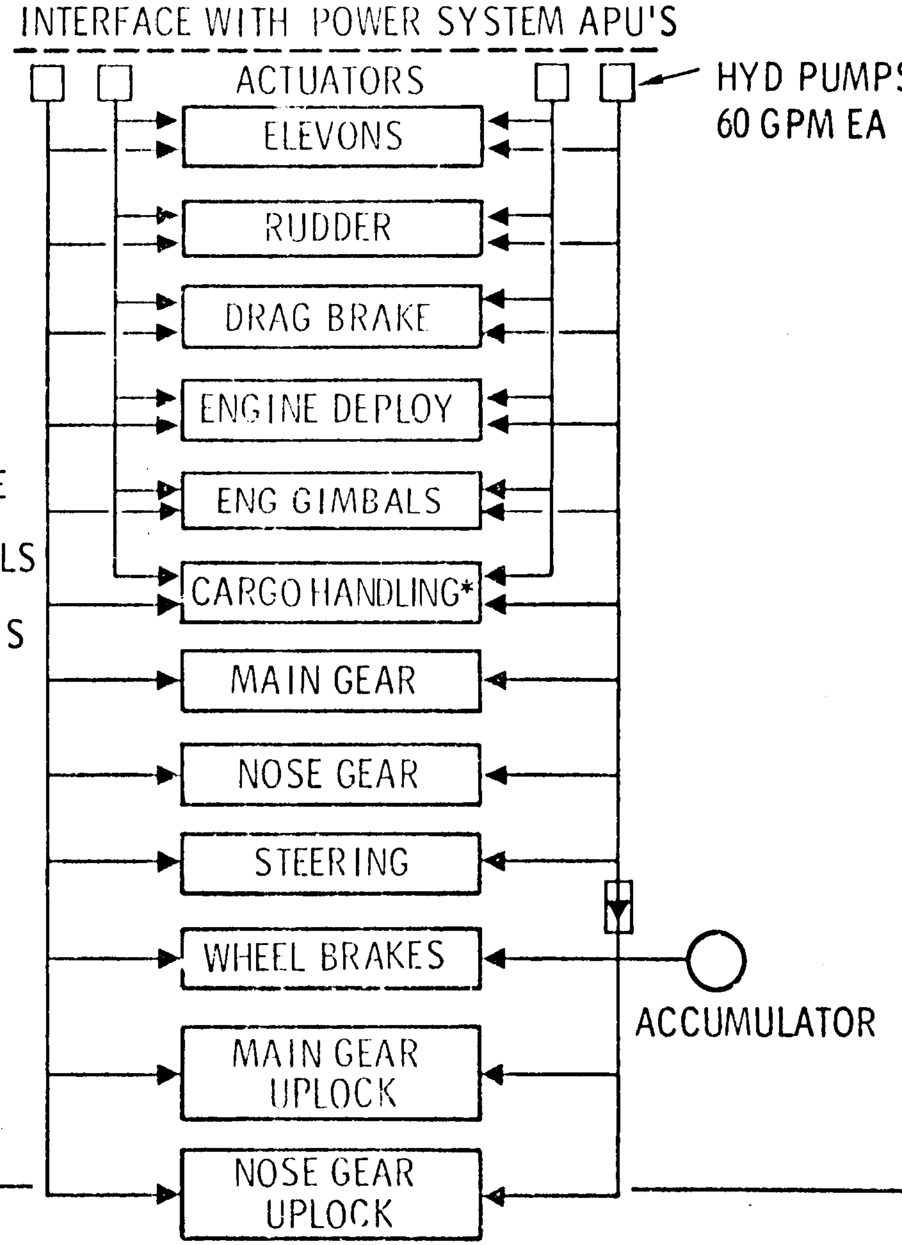
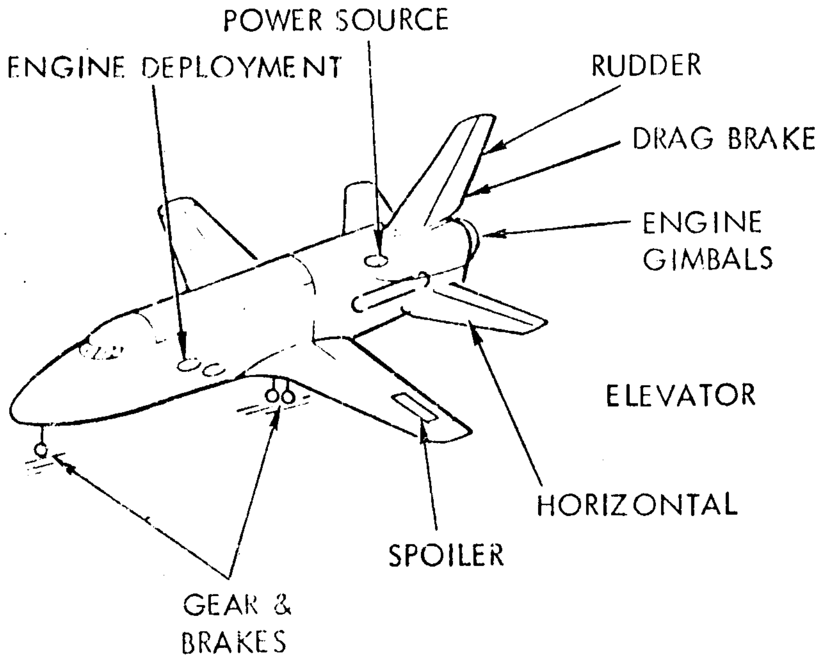
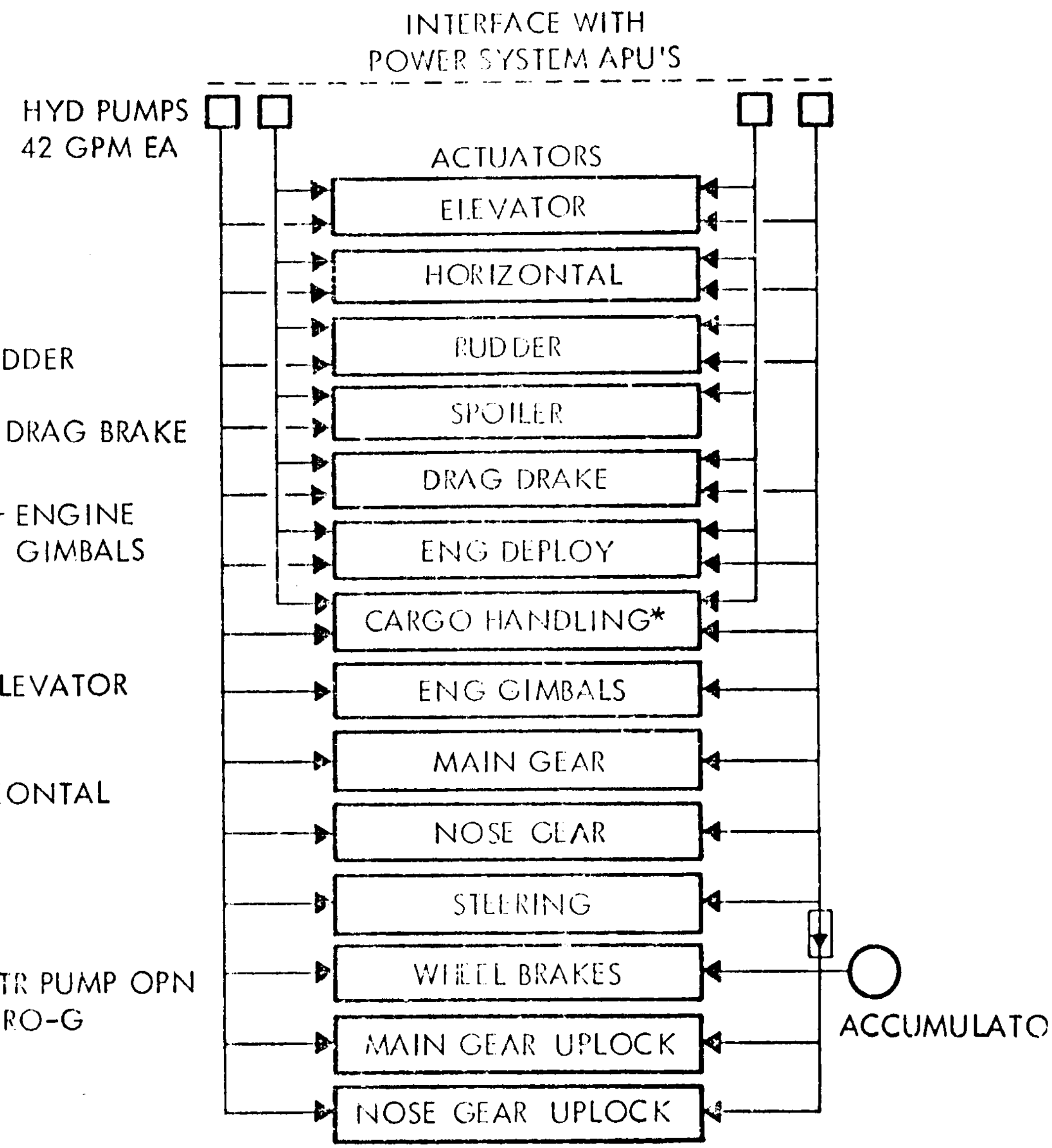


FIGURE 9

HYDRAULIC SYSTEM
STRAIGHT WING ORBITER CONFIGURATION

- -180A CONFIG
- FOUR INDEPENDENT SYSTEMS
- 4000 PSI SYSTEM
- 139 HP APU





*AUX MTR PUMP OPN FOR ZERO-G

FIGURE 10

HYDRAULIC SUBSYSTEM GENERAL DESCRIPTION

PRESSURE	4000 PSI
NO. OF SUBSYSTEMS	4 INDEPENDENT SUBSYSTEMS (FO/FS)
FLUID	CHEVRON M2-V
FLUID TEMPERATURE	-65 F TO +275 F
PLUMBING, FITTING MATERIAL	AM350 STAINLESS STEEL
SEALS MATERIAL	ELASTOMERIC
HEAT REJECTION	APU INLET H_2
ORBITAL HEATING	CIRC PUMPS POWERED BY FUEL CELLS WASTE HEAT FROM ECS INSULATED LINES, LOW HEAT LEAK SUPPORTS
SHAFT HYD HP - STRAIGHT WING	4 X 107 HP
- DELTA WING	4 X 141 HP

FIGURE 11

APU REQUIREMENTS

PROPELLANTS	GH_2 & GO_2
REDUNDANCY	FO/FO/FS ELECTRIC; FO/FS HYDRAULIC
SPEED CONTROL	MIL-STD-704, ELECTRICAL REQUIREMENTS FOR GENERATOR
AMBIENT TEMP.	$-65^{o}F$ TO $+300^{o}F$
LIFE	1,000 HOURS
INSTALLATION	SELF-CONTAINMENT FOR TURBINE, ALL ATTITUDE OPERATION
GROUND OPERATION	APU TO BE USED FOR CHECKOUT OF HYDRAULIC & ELECTRICAL SYSTEMS

FIGURE 12

BOOSTER

ACPS & APU EQUIPMENT LOCATION

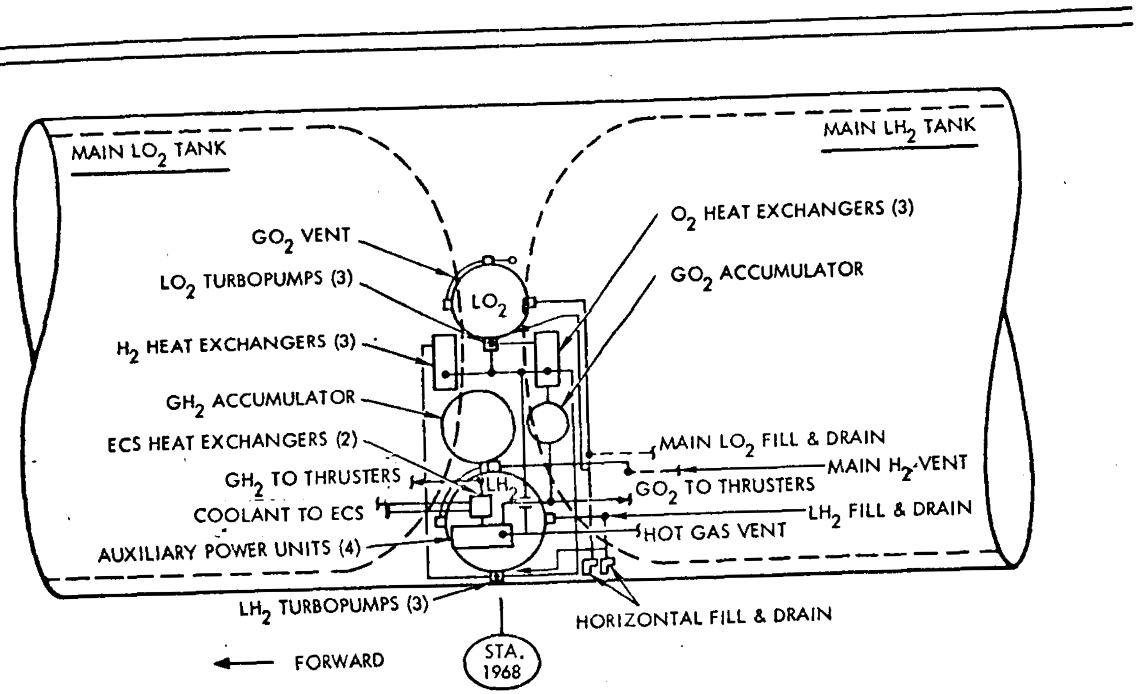
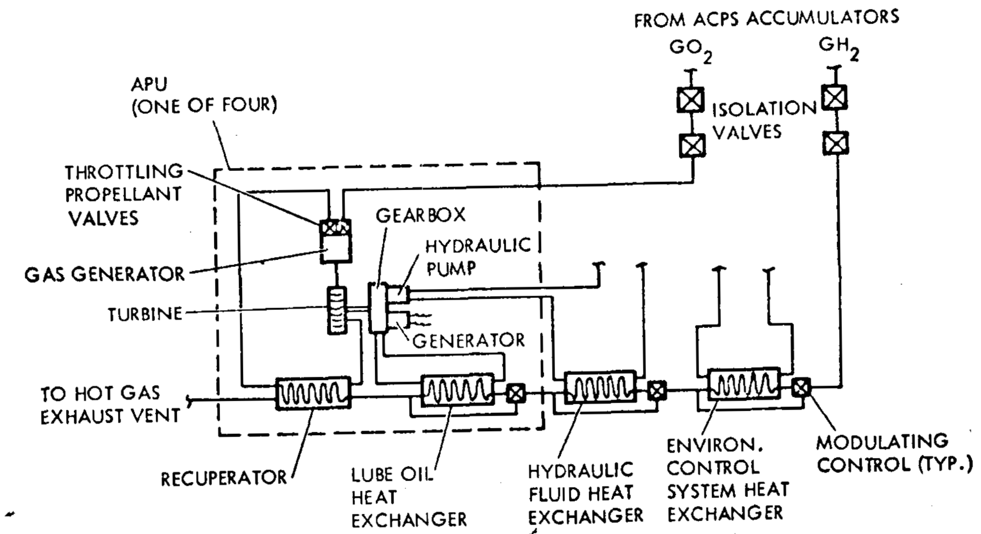


FIGURE 13

BOOSTER

AUXILIARY POWER UNIT



APU DATA (PER APU)	
WEIGHT	323 LB.
PROPELLANT FLOW	
MAX.	930 LB./HR.
AVG.	242 LB./HR.
MIXTURE RATIO	0.6

FIGURE 14

APU LOAD PROFILE

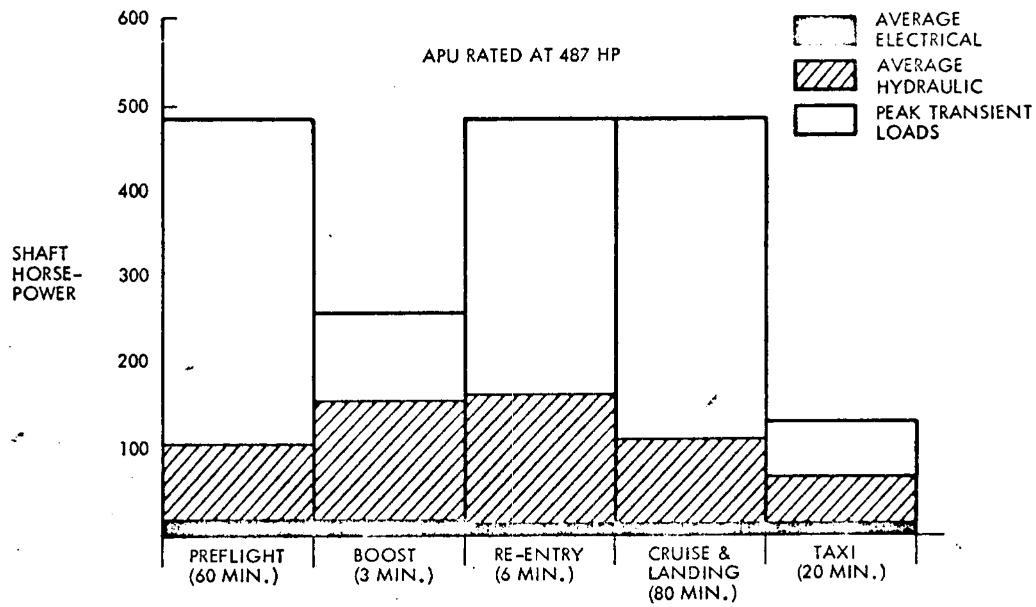


FIGURE 15

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